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G. S. Bañuelos^a; S. Pasakdee^a; J. W. Finley^b

^a USDA-ARS Water Management Research Lab., Parlier, California, USA ^b USDA-ARS Human Nutrition Research Center, Grand Forks, North Dakota, USA

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Growth Response and Selenium and Boron Distribution in Broccoli Varieties Irrigated with Poor Quality Water

G. S. Bañuelos,^{1,*} S. Pasakdee,¹ and J. W. Finley²

¹USDA-ARS Water Management Research Lab., Parlier,
California, USA

²USDA-ARS Human Nutrition Research Center, Grand Forks,
North Dakota, USA

ABSTRACT

Selenium (Se), and boron (B), and salinity contamination of agricultural drainage water is potentially hazardous for water reuse strategies in central California. This greenhouse study assessed tolerance and Se, B, and chloride (Cl⁻) accumulation in different varieties (Emerald City, Samurai, Greenbelt, Marathon) of broccoli (*Brassica oleracea* L.) irrigated with water of the following different qualities: (1) non-saline [electrical conductivity (EC) of <1 dS m⁻¹]; (2) Cl⁻/sulfate salinity of ~5 dS m⁻¹, 250 µg Se L⁻¹, and 5 mg B L⁻¹; and (3) non-saline and 250 µg Se L⁻¹. One hundred and ten days after transplanting, plants were harvested and dry weight (DW) yields and plant accumulation of Se, B, and Cl⁻ was

*Correspondence: G. S. Bañuelos, USDA-ARS Water Management Research Lab., 9611 S. Riverbend Ave., Parlier, CA 93648, USA; E-mail: gbanuelos@fresno.ars.usda.gov.

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evaluated in floret, leaf, and stem. Irrespective of treatments floret yields from var. Samurai were the lowest among all varieties, while floret yields from var. Marathon were the only variety to exhibit some sensitivity to treatments. For all varieties, plant Se concentrations were greatest in the floret (up to $51 \text{ mg kg}^{-1} \text{ DW}$) irrespective of treatment, and B and Cl^- concentrations were greatest in the leaves; $110 \text{ mg B kg}^{-1} \text{ DW}$ and $5.4\% \text{ Cl}^-$, respectively. At post harvest, treatment 2 (with salinity, B, and Se) increased soil salinity to almost 6 dS m^{-1} , total Se concentrations to a high of $0.64 \text{ mg kg}^{-1} \text{ DW}$ soil, and water soluble B concentrations to a high of 2.3 mg B L^{-1} ; soluble Se concentrations were insignificant. The results indicate that var. Emerald City, Greenbelt, and Marathon should be considered as recipients of moderately saline effluent enriched with Se and B under field conditions.

Key Words: Broccoli; Selenium; Boron; Salinity.

INTRODUCTION

Water reuse strategies are under consideration in central California and in many regions of the western United States due to growing municipal and environmental demands for good quality water, as well as the need for drainage water disposal. In the westside of central California, agricultural drainage water contains elevated levels of salinity, and such naturally occurring trace elements as selenium (Se) and boron (B).

The presence of Se is of particular concern, because it was reported to cause toxicity in many biological ecosystems.^[1] Subsequently, soluble Se originating from irrigated agricultural soils or from underlying shallow-groundwater has been strictly monitored in drainage water produced in the westside of central California. If the reuse of saline drainage water becomes a management option for growers on the westside of central California,^[2] then Se deposited onto soils after irrigation with Se-laden drainage water must be managed to minimize its movement into the biological environment.^[3] Moreover, accumulation of Se by plants irrigated with such a water should be monitored, although high sulfate concentrations in drainage water will reduce Se uptake by plants.^[4]

Earlier research showed that such *Brassica* species as Indian mustard and canola accumulate Se as selenate under moderately high chloride salinity and B conditions.^[5,6] Selenate is one form of soluble Se that is most commonly found in subsurface drainage waters in Central California. Selenate is physically and chemically similar to sulfate and hence is believed to be taken up and assimilated by the enzymes of the sulfate assimilation pathway.^[7] Because *Brassica* species, e.g., Indian mustard, canola, broccoli, are recognized as



having a strong affinity for sulfate, they would be expected to absorb soluble selenate if it is available for plant uptake.^[8]

Identifying high cash value crops such as broccoli that accumulate Se and tolerate moderately high levels of Cl^- /sulfate salinity and B, may encourage growers to use them in crop rotation as part of the water reuse strategies under consideration for high Se regions of the western United States. Irrigating broccoli with Se-laden water may also produce a crop that is a potential source of supplemental Se for humans.^[9,10] Thus, our objective was to evaluate growth response and Se and B distribution in four potential salt and B tolerant varieties of broccoli irrigated with poor quality saline water containing Se and B.

MATERIALS AND METHODS

Growth response and Se, Cl^- , and B accumulation by four varieties of broccoli (*Broccoli oleracea* L.); Emerald City, Samurai, Greenbelt, and Marathon that were irrigated with poor quality water, were investigated under greenhouse conditions in Fresno, CA during the fall of 2000. These broccoli varieties were selected after preliminary screening showed that these varieties exhibited a moderate salt and B tolerance at germination (seed donated by Sakata Seed Co., Salinas, CA). In this study, plants were grown in flats and then transplanted as 3-week-old seedlings into 18-L plastic pots filled with 10 kg of typical surface (0–25 cm) air-dried soil (Ciervo clay, saline-sodic fine, montmorillonite, thermic vertic Haplocambid) collected from the westside of the San Joaquin Valley in central California. Selected preplant soil properties prior to treatments were as follows: electrical conductivity (EC) of 1.08 dS m^{-1} , total Se of $0.29 \mu\text{g g}^{-1}$ soil, water soluble B of 0.3 mg L^{-1} , total B of 27 mg kg^{-1} soil, and a pH of 7.6. The soil was mixed thoroughly by a mechanical mixer and passed through a 5 mm sieve before being placed into growing pots.

In preparation for planting, soil in each pot was brought to ~100% field capacity by adding deionized water from the top and bottom by water absorption. Soils were allowed to dry to about 70% of soil field capacity and a preplant fertilizer of 15–15–15 (N–P–K at a rate equivalent to 140 kg ha^{-1}) was applied to all pots (broccoli is generally moderately to heavily fertilized). Each pot initially received three transplants and then reduced to two plants 14 d after transplanting.

The experimental design was completely randomized with six replicates for each irrigation treatment for each variety. Broccoli varieties were irrigated after thinning to two plants with water of one of the following qualities: (1) non-saline water ($\text{EC} < 1 \text{ dS m}^{-1}$) and containing negligible concentrations of Se

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and B; (2) saline water [EC of $\approx 5 \text{ dS m}^{-1}$ (added as Na_2SO_4 , NaCl , and CaCl salts; 10:30:2 moles ratio)] containing $250 \mu\text{g Se L}^{-1}$ (as sodium selenate) and 5 mg B L^{-1} (as boric acid); and (3) non-saline water ($\text{EC} < 1 \text{ dS m}^{-1}$) containing $250 \mu\text{g Se L}^{-1}$ and a negligible concentration of B. The chosen Se and B concentrations, salinity and SO_4 levels were lower than typical levels reported by Shennan et al.^[11] for drainage effluent produced in saline soils of central California. Plants were irrigated based upon approximated evapotranspiration losses (determined by weighing pots for each treatment); the same amount of water was applied to all varieties of broccoli for each respective treatment. For all plants, drainage trays were placed under pots to capture any leachate, which was carefully reapplied to pots. Plants were grown under controlled greenhouse temperature of $23 \pm 2^\circ\text{C}$ and an average photosynthetic photon flux of approximately $400 \mu\text{mol m}^{-2} \text{ s}^{-1}$.

All varieties were harvested after 110 d of growth after transplanting (based upon premature flowering observed in broccoli varieties exposed to treatment 2). Above- and below-ground plant material was removed from pots and separated into florets, leaves, and stems. Plant material was washed with deionized water, oven-dried at 50°C for 7 d, weighed and ground in a stainless steel Wiley mill equipped with a 1 mm screen. After harvest, soil was thoroughly mixed in each pot, and a $\sim 500 \text{ g}$ soil sample was collected without plant residue and passed through a 2 mm sieve. Each soil sample was dried at 50°C for 7 d and ground to pass an $850 \mu\text{m}$ sieve. Our preliminary evaluations showed that using drying temperatures $< 60^\circ\text{C}$ for plant and soil samples reduces any potential loss of Se through volatilization during sample dehydration. Water-soluble fractions of soil Se and B, and EC were determined from a soil water extract of $\sim 1:1$. Plant Se and B and total soil Se was determined in a 500 mg ground soil sample after wet acid digestion with nitric acid, hydrogen peroxide, and hydrochloric acid.^[12,13] Both plant and soil samples were analyzed for Se by atomic absorption spectrophotometry (Thermo Jarrell Ash, Smith Hieftje 1000, Franklin, MA) with an automatic vapor accessory (AVA 880). The National Institute of Standards and Technology (NIST) Standard Wheat Flour [standard reference materials (SRM) 1567, Se content of $1.1 \pm 0.2 \mu\text{g g}^{-1} \text{ DW}$, with a recovery of 94%] and coal fly ash (SRM 1633; Se content of $10.3 \pm 0.06 \mu\text{g g}^{-1}$, with a recovery of 92%) were both dried and treated as normal plant and soil samples and used as an external quality control for Se analyses of plant and soil samples, respectively. Boron was determined by inductive coupled plasma emission spectrometry (Perkin Elmer Plasma 2000 Emission Spectrometer, Norwalk, CT). The Model 160 Conductivity/Salinity Meter was used for measurement of soil EC. Plant samples were extracted with 2% acetic acid and tissue Cl^- concentrations were determined by coulometric-ampereometric titration.^[14]



RESULTS

Dry Weight

Among the tissues sampled, the florets are the marketable product of concern. The only varietal difference in floret dry weight (DW) due to treatment was observed in var. Marathon; floret DW of the other varieties seem to be insensitive to treatments. The floret DW was significantly lower in var. Samurai than the other varieties by at least 50%, however, treatments had no significant effect on its floret DW. Among the plant tissues evaluated, the leaf DWs were the greatest (Tables 1–3); they were not affected by the treatments (Table 2). Stem yields were only affected by treatments in var. Marathon and Emerald City (Table 3).

Tissue Selenium Concentrations

For all broccoli varieties, Se concentrations were greatest in the floret and lowest in the stems, irrespective of treatment (Tables 1–3). Varietal differences were not consistently observed to be influential in the accumulation of Se in the tested organs (Tables 1–3). Selenium concentrations were greatest for all plant tissues with treatment 3 (without salinity and B) for all varieties.

Tissue Boron Concentrations

For all broccoli varieties, plant B concentrations were greatest in the leaves and lowest in both floret and stems with treatment 2 (salinity, Se and B). Generally varietal differences were not observed to be influential in the accumulation of B in the tested tissues among all varieties (Tables 1–3).

Tissue Cl^- Concentrations

For all broccoli varieties, Cl^- concentrations were greatest in leaves and lowest in florets for all treatments (Tables 1 and 2). Irrespective of plant tissue, Cl^- concentrations were greatest with treatment 2 (salinity, Se, and B). Var. Samurai accumulated the greatest Cl^- concentrations in the leaves and florets. A significant correlation between tissue Cl^- concentration and leaf yield was only found in leaves of var. Emerald City ($r = 0.52$) at the $P < 0.05$ level.



Table 1. Dry weight yields and Se, B, and Cl^- accumulation in florets from different varieties of broccoli irrigated with poor quality water.

Variety	Treatment ^a	Plant concentrations			
		DW (g)	Se (mg kg^{-1} , DW)	B (mg kg^{-1} , DW)	Cl^- (mg kg^{-1} , DW)
Emerald city	1	11.6 ^b d ^c (1.5)	0.5 e (0.1)	20 bc (4)	3051 ef (313)
	2	13.3 cd (1.8)	7 d (0.4)	16 cd (2)	4799 b (607)
	3	11.9 d (1.4)	49 ab (3.9)	24 ab (4)	3793 cd (510)
Greenbelt	1	13.5 bcd (0.4)	0.7 e (0.2)	22 ab (3)	3281 de (248)
	2	13.0 cd (1.1)	7 d (0.2)	19 bc (2)	4725 b (314)
	3	12.9 cd (0.4)	47 b (2.2)	25 a (3)	3289 de (422)
Marathon	1	16.6 a (2.8)	0.4 e (0.3)	20 bc (5)	1869 gh (86)
	2	14.0 bc (1.0)	7 d (0.8)	11 e (2)	2475 fg (137)
	3	15.5 ab (2.8)	43 c (1.9)	21 ab (3)	1623 h (168)
Samurai	1	5.9 e (1.6)	0.5 e (0.2)	19 bc (1)	3976 c (404)
	2	5.7 e (1.6)	8 d (0.8)	21 ab (3)	6408 a (372)
	3	5.7 e (0.4)	51 a (4.4)	22 ab (4)	4756 b (666)

^aTreatments are as follows: (1) non-saline water ($<1 \text{ dS m}^{-1}$) and negligible concentrations of Se and B; (2) saline water (5 dS m^{-1}), $250 \mu\text{g Se L}^{-1}$, and 5 mg B L^{-1} ; (3) non-saline water ($<1 \text{ dS m}^{-1}$), $250 \mu\text{g Se L}^{-1}$, and negligible concentrations of B.

^bValues represent the mean from six replications with the standard deviation in parentheses.

^cMeans within each column followed by the same letter are not significantly different at the $P < 0.05$ level by Fisher's LSD test.



Table 2. Dry weight yields and Se, B, and Cl^- accumulation in leaves from different varieties of broccoli irrigated with poor quality water.

Variety	Treatment ^a	Plant concentrations			
		DW (g)	Se (mg kg^{-1} , DW)	B (mg kg^{-1} , DW)	Cl^- (mg kg^{-1} , DW)
Emerald city	1	26.5 ^b bc ^c (3.6)	0.2 e (0.1)	22 def (4)	22487 ef (2138)
	2	23.1 c (2.4)	6 d (0.7)	110 a (18)	52991 ab (8695)
	3	24.4 c (2.7)	28 bc (3.8)	29 d (4)	25629 de (4671)
Greenbelt	1	28.0 bc (1.7)	0.5 e (0.2)	17 ef (2)	28744 de (4298)
	2	26.9 bc (1.5)	6 c (0.8)	91 b (14)	43244 bc (6137)
	3	23.0 c (5.2)	31 a (7.1)	23 de (7)	33304 cd (11532)
Marathon	1	23.7 de (2.4)	0.2 e (0.1)	14 f (3)	19969 ef (1426)
	2	20.6 e (4.2)	6 d (0.5)	44 c (5)	34010 cd (2631)
	3	23.8 de (4.1)	26 c (1.3)	15 f (4)	14577 f (2277)
Samurai	1	30.8 abc (4.1)	0.3 e (0.1)	28 de (5)	25729 de (4822)
	2	31.7 ab (2.8)	7 d (0.9)	91 b (10)	57466 a (6951)
	3	36.5 a (0.6)	30 ab (3.5)	32 d (4)	33307 cd (6713)

^aTreatments are as follows: (1) non-saline water ($<1 \text{ dS m}^{-1}$) and negligible concentrations of Se and B; (2) saline water (5 dS m^{-1}), $250 \mu\text{g Se L}^{-1}$, and 5 mg B L^{-1} ; (3) non-saline water ($<1 \text{ dS m}^{-1}$), $250 \mu\text{g Se L}^{-1}$, and negligible concentrations of B.

^bValues represent the mean from six replications with the standard deviation in parentheses.

^cMeans within each column followed by the same letter are not significantly different at the $P < 0.05$ level by Fisher's LSD test.



Table 3. Dry weight yields and Se, B, and Cl^- accumulation in stems from different varieties of broccoli irrigated with poor quality water.

Variety	Treatment ^a	Plant concentrations			
		DW (g)	Se (mg kg^{-1} , DW)	B (mg kg^{-1} , DW)	Cl^- (mg kg^{-1} , DW)
Emerald city	1	14.6 ^b abc ^c (2.9)	0.3 d (0.1)	19 c (6)	23021 bc (4389)
	2	13.1 c (1.6)	4 c (0.6)	26 a (3)	38929 a (2142)
	3	15.8 ab (2.0)	23 ab (2.2)	13 d (2)	20001 cd (2246)
Greenbelt	1	13.5 bc (2.0)	0.4 d (0.3)	17 cd (4)	24767 bc (1549)
	2	13.4 c (1.5)	4 c (0.7)	24 ab (2)	27324 b (4517)
	3	14.1 abc (1.9)	22 a (4.0)	15 d (3)	20625 cd (4471)
Marathon	1	16.0 a (0.9)	0.3 d (0.0)	20 bc (3)	11364 e (515)
	2	13.6 bc (1.7)	3 c (0.7)	20 bc (4)	19268 cd (1165)
	3	15.0 abc (0.8)	19 b (1.8)	18 c (2)	11425 e (869)
Samurai	1	14.9 abc (1.3)	0.3 d (0.1)	20 bc (1)	14745 e (1661)
	2	13.0 c (1.7)	4 c (0.3)	27 a (2)	20448 cd (2294)
	3	13.4 c (1.1)	28 a (1.4)	24 ab (3)	17686 cd (1810)

^aTreatments are as follows: (1) non-saline water ($<1 \text{ dS m}^{-1}$) and negligible concentrations of Se and B; (2) saline water (5 dS m^{-1}), $250 \mu\text{g Se L}^{-1}$, and 5 mg B L^{-1} ; (3) non-saline water ($<1 \text{ dS m}^{-1}$), $250 \mu\text{g Se L}^{-1}$, and negligible concentrations of B.

^bValues represent the mean from six replications with the standard deviation in parentheses.

^cMeans within each column followed by the same letter are not significantly different at the $P < 0.05$ level by Fisher's LSD test.



Influence on Soil Properties

Soil salinity increased to a high of almost 6 dS m^{-1} at harvest for treatment 2 (salinity, Se, and B) for all varieties and to $1.0\text{--}1.3 \text{ dS m}^{-1}$ in soils for treatments 1 and 3 (Table 4). Concentrations of the primary extractable ions associated with salinity in this study, i.e., SO_4^{2+} , and Cl^- , significantly increased in the soil at harvest for treatment 2 for all varieties (Table 4). Only trace amounts of extractable Se ($<0.004 \text{ mg L}^{-1}$) were measured at harvest for treatment 2 for all varieties (Table 4). Total Se concentrations increased from a low of 0.29 (control) to a high of 0.64 mg kg^{-1} (treatment 2) at harvest for all varieties. Water extractable B increased at harvest to a high of 2.3 mg B L^{-1} for treatment 2 (salinity, Se and B) for all varieties and was $<1 \text{ mg B L}^{-1}$ in soils from treatments 1 and 3. Soil pH was ≈ 7.7 at harvest for all treatments and varieties.

DISCUSSION

Data from this study indicate that the selected broccoli varieties tolerated irrigation with poor quality water (containing salinity, B, and Se) under greenhouse conditions. Biomass production in the tested tissues was generally not affected by the treatments. Floret yields were, however, significantly lower in var. Samurai than the other varieties. Although varietal differences in Se accumulation were not observed, Se accumulation was generally lower for all tissues exposed to saline and B levels in treatment 2 compared to treatments 1 and 3. The greatest accumulation of Se in the floret compared to other tissues is characteristic of a protein-rich organ from a species such as *Brassica* that has a high sulfur requirement. Selenium is likely incorporated into Se-amino acids such as Se-methylselenocysteine, selenocystathione and Se-methyl-selenomethionine and replaced sulfur-amino acids as components of proteins.^[15]

Successful reuse of water containing salinity and B for producing Se-enriched broccoli under field conditions will be dependent on the ability of the selected broccoli variety to tolerate increasing soil salinity and to accumulate Se under increasing soil sulfate salinity levels in the soil. Increased soil salinity and extractable B levels at harvest and high concentrations of tissue Cl^- for all varieties irrigated with treatment 2 (salinity, B, and Se) is an indication that broccoli yield and quality may decrease over time if salt and B management practices, i.e., leaching, applying gypsum are not periodically employed under field conditions.^[16–19] Although var. Emerald City, Greenbelt, and Marathon produced similar floret yields with all treatments, var. Marathon may be the variety of choice with long term use of poor water quality because of its lower accumulation of Cl^- and B compared to other varieties.

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Table 4. Post harvest concentrations of selected water extractable ions, electrical conductivity, and pH in soils from different varieties of broccoli irrigated with poor quality water.

Variety	Treatment ^a	Extractable concentrations					Total Se (mg kg ⁻¹)	Other parameters	
		Se (μg L ⁻¹)	B (mg L ⁻¹)	Cl ⁻ (mg L ⁻¹)	SO ₄ (mg L ⁻¹)			pH	EC (dS m ⁻¹)
Samurai	1	0 ^b b ^c (0)	0.6 b (0.1)	121 b (11)	64 b (6)		0.33 b (0.04)	7.7 ns (0.1)	1.0 b (0.1)
	2	4 a (2)	2.1 a (0.2)	1287 a (89)	390 a (16)		0.59 a (0.06)	7.7 ns (0.1)	5.4 a (0.2)
	3	0 b (0)	0.6 b (0.1)	124 b (15)	56 b (9)		0.32 b (0.04)	7.7 ns (0.1)	1.1 b (0.1)
Greenbelt	1	0 b (0)	0.6 b (0.1)	129 b (7)	64 b (10)		0.30 b (0.04)	7.8 ns (0.1)	1.1 b (0.1)
	2	1 a (1)	2.2 a (0.2)	1246 a (45)	394 a (24)		0.64 a (0.05)	7.7 ns (0.1)	5.8 a (0.2)
	3	0 b (0)	0.7 b (0.1)	122 b (9)	61 b (3)		0.29 b (0.02)	7.8 ns (0.1)	1.1 b (0.1)
Emerald city	1	0 b (0)	0.6 b (0.1)	109 b (11)	57 b (6)		0.35 b (0.02)	7.7 ns (0.1)	1.2 b (0.1)
	2	3 a (1)	2.3 a (0.1)	1280 a (35)	372 a (8)		0.53 a (0.05)	7.8 ns (0.1)	5.8 a (0.2)
	3	0 b (0)	0.6 b (0.1)	126 b (6)	68 b (5)		0.34 b (0.02)	7.7 ns (0.1)	1.3 b (0.1)
Marathon	1	0 b 0	0.7 b (0.1)	126 b (7)	64 b (8)		0.30 b (0.02)	7.8 ns (0.1)	1.1 b (0.1)
	2	2 a 0	2.2 a (0.2)	1276 a (23)	382 a (20)		0.57 a (0.04)	7.8 ns (0.1)	5.8 a (0.2)
	3	0 b 1	0.7 b (0.0)	124 b (5)	63 b (8)		0.33 b (0.02)	7.7 ns (0.1)	1.0 b (0.1)

^aTreatments are as follows: (1) non-saline water (<1 dS m⁻¹) and negligible concentrations of Se and B; (2) saline water (5 dS m⁻¹), 250 μg Se L⁻¹ and 5 mg B L⁻¹; (3) non-saline water (<1 dS m⁻¹), 250 μg Se L⁻¹, and negligible concentrations of B.

^bValues represent the mean from six replicates with the standard deviation in parentheses.

^cMeans within each column followed by the same letter are not significantly different at the $P < 0.05$ level by Fisher's LSD test.



The potential phytotoxicity of B and its immobility in the root zone may generally be a limitation to water reuse programs where irrigation water contains high B at concentrations of 5 mg L^{-1} or greater; this may be a less of a problem in a short season crop such as broccoli. In this regard, Letey et al.^[2] have reported that increased soil salinity may also reduce B movement to the plant and hence result in a reduction of B toxicity symptoms. Although typical salt or B toxicity symptoms, e.g., necrosis of leaf margins were not observed, the salts likely induced the premature bolting observed in broccoli varieties exposed to treatment.

Broccoli's ability to absorb selenate applied via water treatments and to volatilize Se,^[20] and the possible reduction of some selenate to insoluble forms of Se in the soil,^[21] likely helped minimize a buildup of extractable soil Se at post harvest for all varieties. The phytoextraction of extractable Se by broccoli has been recently reported by Bañuelos^[10] under field conditions. If, however, concentrations of extractable Se are only a very small fraction of the total soil Se concentration (as observed in soils at preplant in this study), then broccoli was ineffective in absorbing Se and lowering the total soil Se concentration. Moreover, selenium uptake will be hindered by high sulfate concentrations in the soil. Because of new regulations regarding the loads of Se leaving field sites in Se-rich regions of central California, irrigation of field-grown broccoli with Se-laden water will necessitate a strict monitoring of soluble Se throughout the soil profile as well as in surface runoff and/or in drainage water.

CONCLUSIONS

The accumulation of Se and the positive floret yield responses show that the tested varieties of broccoli should be evaluated under field conditions for consideration as recipients of moderately saline agricultural effluent enriched with Se and B. The yields and accumulation of Se by broccoli will, however, be highly dependent on the salt and B level and sulfate content of the drainage water and their accumulation in the soil. More importantly the attenuation of possible Se accumulation in the soil will be a critical component to manage for sustainable reuse of drainage water of this quality. Although plant accumulation of Se and other biological processes in the soil and plant help minimize the buildup of soluble Se in the soil, future field studies should include evaluating the transformation and reduction of applied selenate to insoluble species of Se, i.e., elemental Se. Practicing good water management and installing subsurface drainage water systems for field conditions and utilizing crop rotations will be essential for long-term use of poor quality water containing salinity and B for growing broccoli.

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REFERENCES

1. Ong, C.G.; Herbel, M.J.; Dahlgren, R.A.; Tanji, K.K. Trace element (Se, As, B) contamination of evaporates in hypersaline agricultural evaporation ponds. *Environ. Sci. Technol.* **1997**, *31*, 831–836.
2. Letey, J.; Grattan, S.; Oster, J.D.; Birkle, J.E. *Findings and Recommendation to Develop the Six-year Activity Plan for the Department's Drainage Reduction and Reuse Program*; Final Rep. Task Order No. 5, Contract No. 98-7200-B80933; California Dept. of Water Resources: Sacramento, CA, 2001.
3. San Joaquin Valley Drainage Program. *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley*; U.S. Dept. Interior and Calif. Resources Agency: Sacramento, CA, 1990; Final Report.
4. Bell, P.F.; Parker, D.R.; Page, A.L. Contrasting selenate-sulfate interactions in selenium-accumulating and non accumulating plant species. *Soil Sci. Soc. Am. J.* **1992**, *56*, 1818–1824.
5. Bañuelos, G.S.; Meek, D.W.; Hoffman, G.J. The influence of selenium uptake in wild mustard. *Plant Soil* **1990**, *127*, 201–206.
6. Bañuelos, G.S.; Cardon, G.E.; Phene, C.J.; Wu, L.; Akohoue, S.; Zambruski, S. Soil boron and selenium removal by three plant species. *Plant Soil* **1993**, *148*, 253–263.
7. Zayed, A.; Pilon-Smits, E.; De Souza, M.; Lin, Z.Q.; Terry, N. Remediation of selenium-polluted soils and waters by phytovolatilization. In *Phytoremediation of Contaminated Soil and Water*; Terry, N., Bañuelos, G.S., Eds.; CRC Press LLC: Boca Raton, FL, 2000; 61–84.
8. Zayed, A.; Lytle, M.; Terry, N. Accumulation and volatilization of different chemical species of selenium by plants. *Planta* **1998**, *206*, 284–292.
9. Finley J.W.; Davis, C.P.; Feng, Y. Selenium from high selenium broccoli protects rats from colon cancer. *J. Nutr.* **2000**, *130*, 2384–2393.
10. Bañuelos, G.S. Canola and broccoli grown as alternative crops for irrigation with drainage water. *J. Environ. Qual.* **2002**, *31*, 1802–1808.
11. Shennan, C.; Grattan, S.R.; May, D.M.; Hillhouse, C.J.; Shachtman, D.P.; Wander, M.; Roberts, B.; Tajoya, S.; Burau, R.G.; McNeish, C.; Zelinski, L. Feasibility of cyclic reuse of saline drainage in a tomato cotton rotation. *J. Environ. Qual.* **1995**, *24*, 476–486.



12. Bañuelos, G.S.; Akohoue, S. Comparison of microwave digestion with block digestion for selenium and boron analysis in plant tissues. *Commun. Soil Sci. Plant Anal.* **1994**, *25*, 1655–1670.
13. Bañuelos, G.S.; Meek D.W. Accumulation of selenium in plants grown on selenium-treated soil. *J. Environ. Qual.* **1990**, *19*, 772–777.
14. Skoog, D.A. *Principles of Instrumental Analysis*, 3rd Ed.; Saunders College: NY, 1985.
15. Anderson, J.W.; Scarf A.R. Selenium and plant metabolism. In *Metals and Micronutrients: Uptake and Utilization by Plants*; Robb, D.A., Pierpoint, W.S., Eds.; Academic Press: New York, 1983; 241–275.
16. Maas, E.V.; Grattan, S.R. Crop yields as affected by salinity. In *Agricultural Drainage*; Skaggs, R.W., Schilfgaarde, J.V., Eds.; Agron. Monogr. No. 38; ASA, CSSA, SSA: Madison, WI, 1999; 55–110.
17. Grattan, S.R.; Rhoades, J.D. Irrigation with saline ground water and drainage water. In *Agricultural Salinity Assessment and Management Manual*; Tanji, K.K., Ed.; ASCE Manuals and Rep. ASCE: NY, 1990; Eng. 71, 432–449.
18. Shannon, M.C.; Grieve, C.M.; Wilson, C.; Poss, J.A.; Suarez, D.L.; Lesch, S.; Rhoades, J.D. Growth and Water Relations of Plant Species Suitable for Saline Drainage Water Reuse Systems; California Dept. of Water Resources: Sacramento, CA, 1998; Final Rep. DWR-B-59922.
19. Ayars, J.E.; Tanji, K.K. Effects of drainage on water quality in arid and semi arid irrigated lands. In *Agricultural Drainage*; Skaggs, R.W., Schilfgaarde, J.V., Eds.; Agron. Monogr. No. 38; ASA, CSSA, SSA: Madison, WI, 1999; 831–870.
20. Terry, N.; Carlson, C.; Raab, T.K.; Zayed, A.M. Rates of selenium volatilization among crop species. *J. Environ. Qual.* **1992**, *21*, 341–344.
21. Tokunaga, T.K.; Pickering, I.J.; Brown, G.E., Jr. Selenium transformations in ponded sediments. *Soil Sci. Soc. Am. J.* **1996**, *60*, 781–790.

